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Cincinnati, Ohio

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ABSTRACT OF

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This paper explores the systematic nonuniformities inherent in multicompartmented baghouse operation, and analyzes the over-all performance in relation to the characteristics of the individual compartments. Those properties of an operating unit which can be used to characterize the installation are delineated, and a methodology developed whereby critical values of these properties may be calculated from easily obtainable field measurements. The critical characteristics are defined as the residual filter drag of a compartment, the terminal filter drag of a compartment, and the residual velocity. The utility of these characteristics to determine the cause of operating difficulties is discussed.

CHARACTERIZATION OF INDUSTRIAL FABRIC FILTERS

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Filtration within multicompartmented fabric filter installations tends to proceed according to definite patterns, knowledge of which will contribute greatly to the solution of many problems which can arise in actual operation. It is the purpose of this paper to briefly explore these patterns and to analyze the over-all performance in relation to the characteristics of individual compartments; to delineate those properties of an operating unit which can be used to characterize the installations; and to develop a methodology for determining critical values of these properties from easily obtainable field measurements.

Internal Operating Characteristics

The concept used for the characterization of multicompartmented baghouses was proposed by Stephan, Walsh and Herrick,[1] and independently utilized by Sargent.[2] This concept is based on the principle that the rate of fluid flow through a filter medium depends on the driving force across the medium and on a property of the system which is termed "filter drag." This property has been described as being analogous to the resistance

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[1] Stephan, D.G., Walsh, G.W., and Herrick, R.A., "Concepts in Fabric Air Filtration," American Industrial Hygiene Association Journal, 21, 1-14 (February 1960).

[2] Sargent, K.H., "Cleaning Iron Oxide Fumes with a Bag Filter," Iron and Coal Trades Review, 178, 79-85 (January 9, 1959).

of an element in an electrical circuit. The term "filter drag" is used herein, rather than the term "resistance" contained in previous papers,[1][2] to avoid confusion with the common usage of the latter term for defining pressure differential.

In a multicompartmented baghouse the individual compartments may be considered resistant elements arranged in parallel with a driving force, the filter pressure differential. The resulting volumetric flow rate is comparable to current flow in amperes. However, since the velocity through a filter unit, such as an individual bag or a compartment, is a more critical measure of performance than the total volumetric flow rate, filter drag is defined as the ratio of filter pressure differential to volumetric flow per unit of filter area, which is equivalent to the ratio of filter pressure differential to filter velocity.

For an electrical system of parallel resistances, (R_1, R_2 $\cdots$, R_n) the effective resistance (R_e) of the circuit may be calculated from the equation:

$$\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n} \qquad (1)$$

Likewise, the effective drag of a baghouse (S_e) may be expressed as a function of the drag of each compartment (S_1, S_2, $\cdots$ S_n) according to the equation:

$$\frac{A_t}{S_e} = \frac{A_1}{S_1} + \frac{A_2}{S_2} + \cdots + \frac{A_n}{S_n} \qquad (2)$$

where A_t is the total filter area of the house, and A_1, A_2, A_n, are the filter areas of the compartments.

The generation of differences in filter drag within a multicompartmented baghouse may be illustrated by considering an ideal situation in which total flow and the particulate load and size distribution are constant, gas temperature is constant, and variations in pressure losses to and from the individual compartments are negligible. When an installation is first put on stream under these conditions, the drag will be essentially the same in all of the various compartments as governed by the permeability of the new fabric, and filtration will proceed at the same rate through all the units for the entire first cycle. At the end of this cycle a unit will be taken out of service for cleaning. Because of the resultant increase in gas flow through the remaining units, the filter pressure will immediately rise. When the cleaned unit is subsequently used for filtration its drag will be less than that of the other compartments so that deposition of dust in this unit will proceed at higher than the average rate. Normally, the other compartments will be cleaned individually at the end of consecutive cycles. A repetition of the above process will take place, and eventually a systematic arrangement of filter drag within the baghouse will develop, as illustrated in Figure 1.

The filter drag profile depicted in Figure 1 has been calculated for an assumed situation, utilizing the relations developed in this study. It represents a six-compartment baghouse just after compartment 6 has been cleaned and put back in service. At this time a definite flow pattern will exist with a maximum velocity in the cleaned unit. Subsequent filtration will alter the velocity pattern, since, for any small increment of

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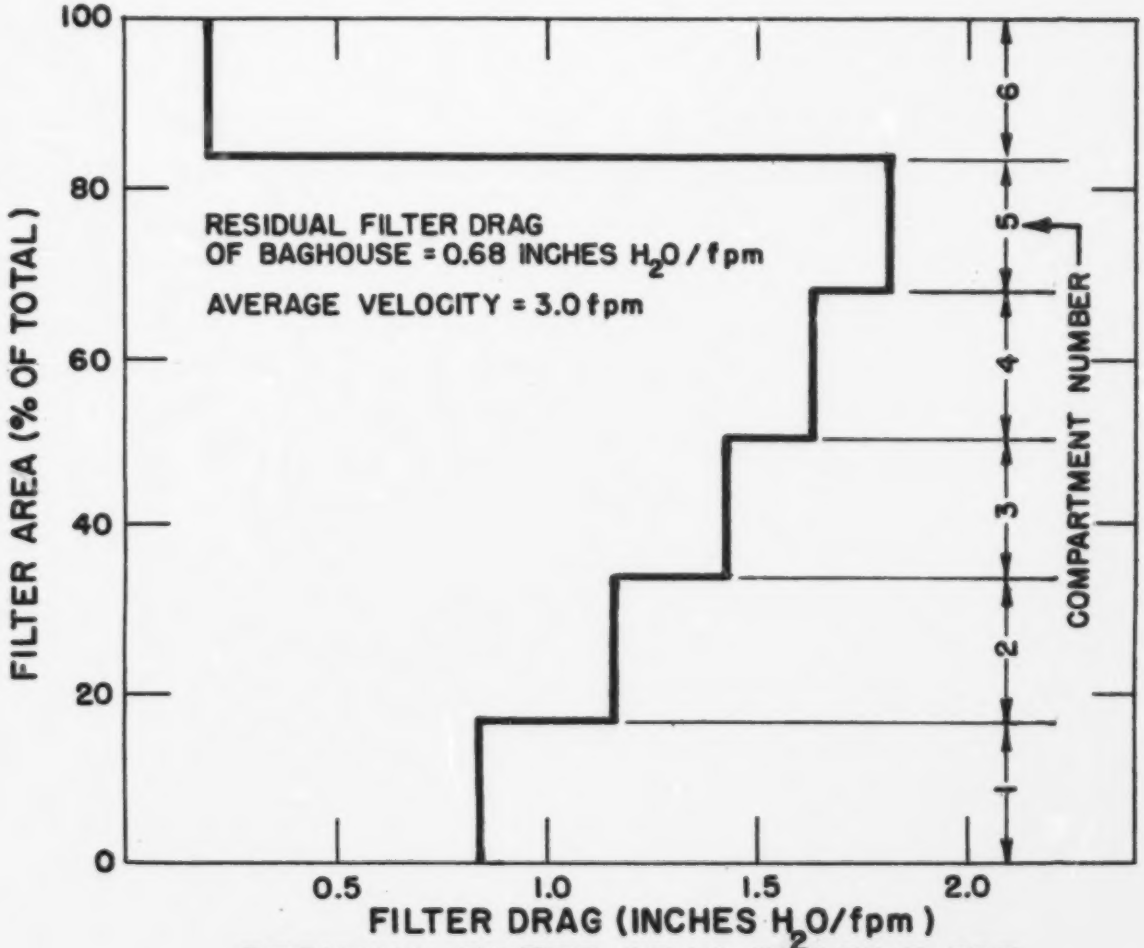


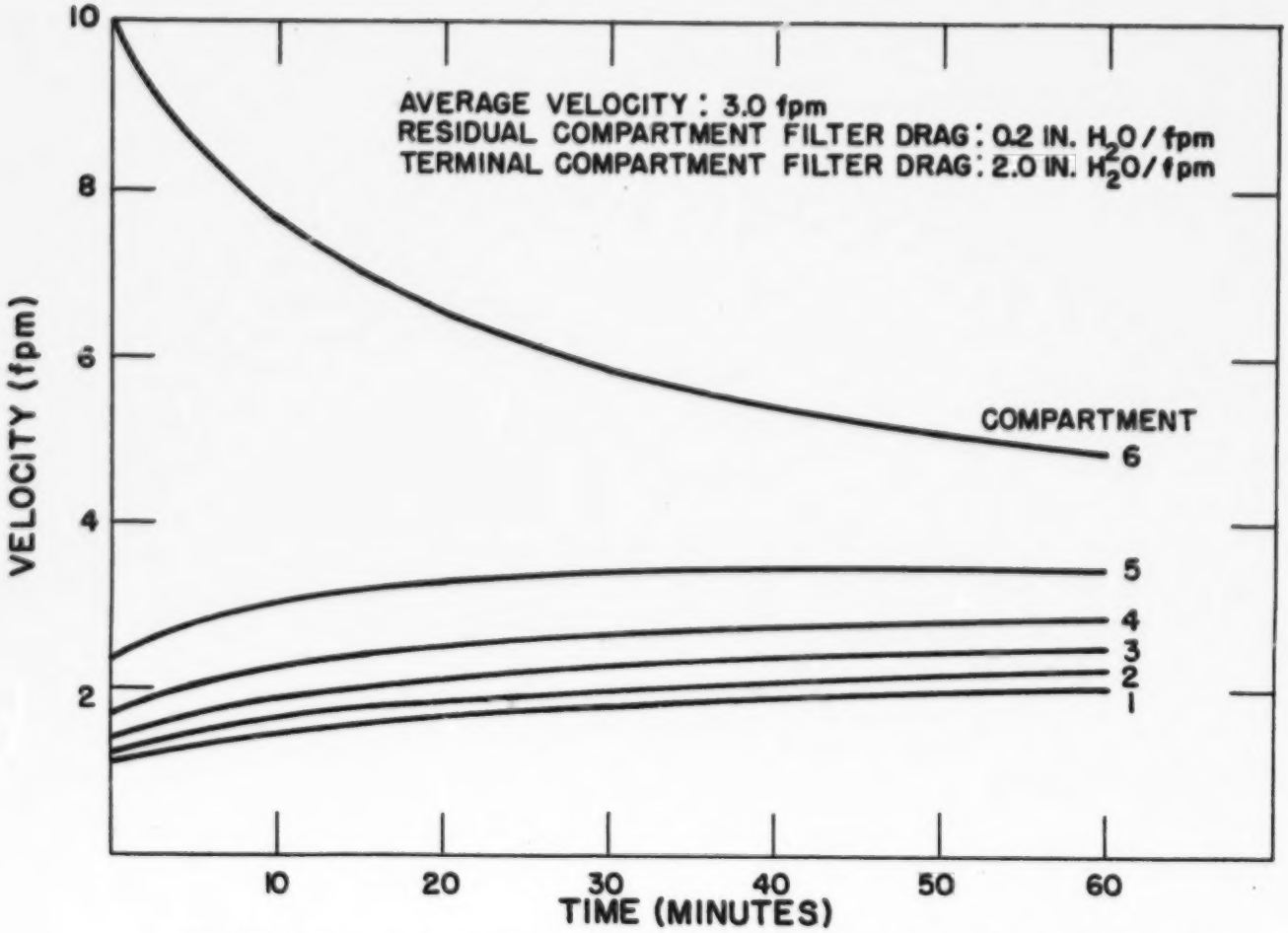
RESIDUAL FILTER DRAG PROFILE FOR SIX COMPARTMENT BAGHOUSE

FIGURE 1

time, the amount of dust deposited in each compartment will be proportional to the average velocity in that compartment at that time. Hence, the drag of the cleaned unit will increase more rapidly than the drag of the other units, resulting in a rapid decrease in average velocity through this compartment.

This effect is illustrated by Figure 2, which represents the velocity pattern as a function of filtration time beginning with the filter drag profile indicated in Figure 1. It is important to realize that even though the average velocity was 3 ft. per minute for the entire period, velocities on the order of 3 times as great occurred in compartment 6. In fact, for only one instant in each cycle does a single compartment experience the nominal velocity of 3 ft. per minute. Velocity variations may also occur from filter to filter and along the length of a filter. Therefore, the usefulness of the nominal velocity as a means to describe filtration is somewhat in question, since for a given nominal velocity many combinations of internal flow distribution may exist.

For a baghouse at equilibrium, the filter drag profile and velocity pattern will be cyclic. For the example cited, compartment 1 will be cleaned on the next cycle, and its flow pattern will be as shown for compartment 6, in Figure 2.



VELOCITY PATTERN IN 6-COMPARTMENT BAGHOUSE AS FUNCTION OF TIME

FIGURE 2

Critical Operating Characteristics

In the discussion which follows, reference will be made to "residual" and "terminal" conditions. Residual conditions are those which exist in a particular compartment as it is put on stream after cleaning, and terminal conditions are those which exist in a compartment just before it is taken out of service for cleaning.

The residual drag and terminal drag establish over-all limits for a particular installation; therefore they are critical operating characteristics. Variations in filter drag also establish differences in filter velocities, which may influence the amount of dust penetration into the filter, filter blinding, and the structure of the dust cake, as discussed by Stephan and Walsh.[3] The residual velocity is therefore also a critical operating characteristic.

These critical operating characteristics may be determined from pressure differential measurements taken across two points common to the inlet and outlet sides of all compartments, if the total flow through the system is known. Such measurements will produce a curve of the type shown in Figure 3.

At time t_a on this figure a freshly cleaned compartment has come on stream, and during the interval t_a-t_b filtration proceeds with a given number of compartments (n). When time t_b is reached one compartment is

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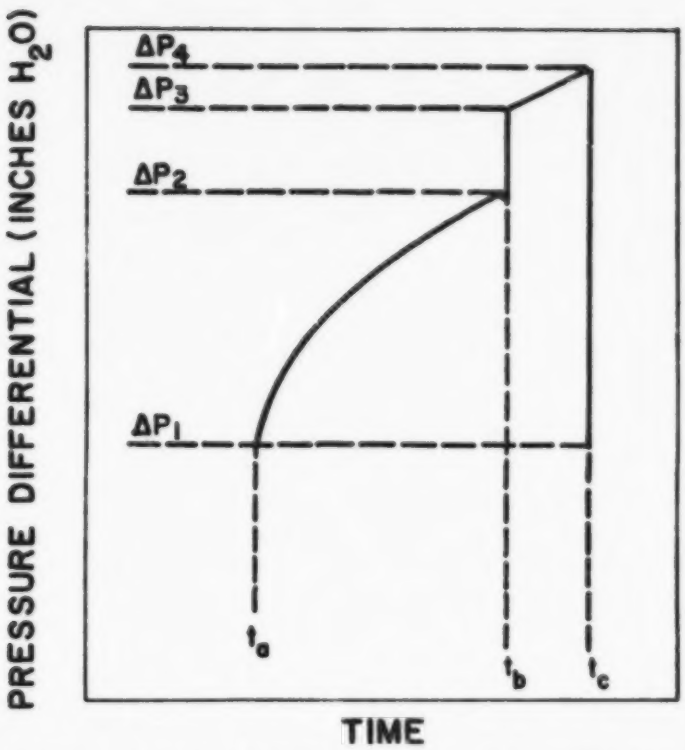
[3]Stephan, D.G. and Walsh, G.W., "The Importance of Residual Mass and Resistance Profiles in Air Filtration," Presented at the Forty-Second National Meeting of American Institute of Chemical Engineers, Atlanta, Georgia, February 21-24, 1960, Preprint No. 12.



SCHEMATIC PRESSURE DIFFERENTIAL CURVE FOR MULTI-COMPARTMENT BAGHOUSE

FIGURE 3

at its terminal condition and is taken out of service for cleaning. The pressure differential immediately increases from ΔP_2 to ΔP_3. During this instant there is no change in the drag of the remaining units as the flow through the filters is laminar. Filtration then proceeds with n-1 compartments until the cleaned filters are back in service. At this time (t_c) the pressure differential decreases from ΔP_4 to ΔP_1. Again, there is no change in the drag of the units continually filtering. These instantaneous changes in pressure differential are indirect measurements of terminal and residual drag in a particular compartment and can be used with the relations which follow to characterize a particular mode of operation.

Considering the filter areas of all compartments as equal, and utilizing equation (1), it can be shown that at time t_b and pressure differential ΔP_2:

$$\frac{n}{S_{e_2}} = \frac{1}{S_t} + \sum \frac{1}{S} \qquad (3)$$

where S_{e_2} is the drag of the house at time t_b and pressure differential ΔP_2, S_t is the terminal drag of the compartment to be cleaned, and $\sum \frac{1}{S}$ represents the combined drag for the remainder of the compartments.

At time t_b, and pressure differential ΔP_3,

$$\frac{n-1}{S_{e_3}} = \sum \frac{1}{S} \qquad (4)$$

since the combined drag for the remaining compartments has not changed. S_{e_3} is the drag of the house after the compartment to be cleaned has been taken off-stream.

Equations (3) and (4) may be combined to give:

$$\frac{n}{S_{e_2}} - \frac{n-1}{S_{e_3}} = \frac{1}{S_t} \tag{5}$$

which is readily solved for the terminal drag of a compartment.

A similar treatment may be applied to solve for the residual drag of a compartment (S_R) in which case the final equation is:

$$\frac{n}{S_{e_1}} - \frac{n-1}{S_{e_4}} = \frac{1}{S_R} \tag{6}$$

where S_{e_4} and S_{e_1} are the effective drags of the baghouse at times t_b and t_c when the house pressure differential is ΔP_4 and ΔP_1 respectively.

The residual velocity, u_{f_r}, may be calculated from S_{e_1} and S_R as follows:

$$S_{e_1} = \frac{\Delta P_1}{u_f} \tag{7}$$

and

$$S_R = \frac{\Delta P_1}{u_{f_R}} \tag{8}$$

therefore,

$$\frac{u_{f_R}}{u_f} = \frac{S_{e_1}}{S_R} \tag{9}$$

where u_f is the average house velocity with all compartments in service.

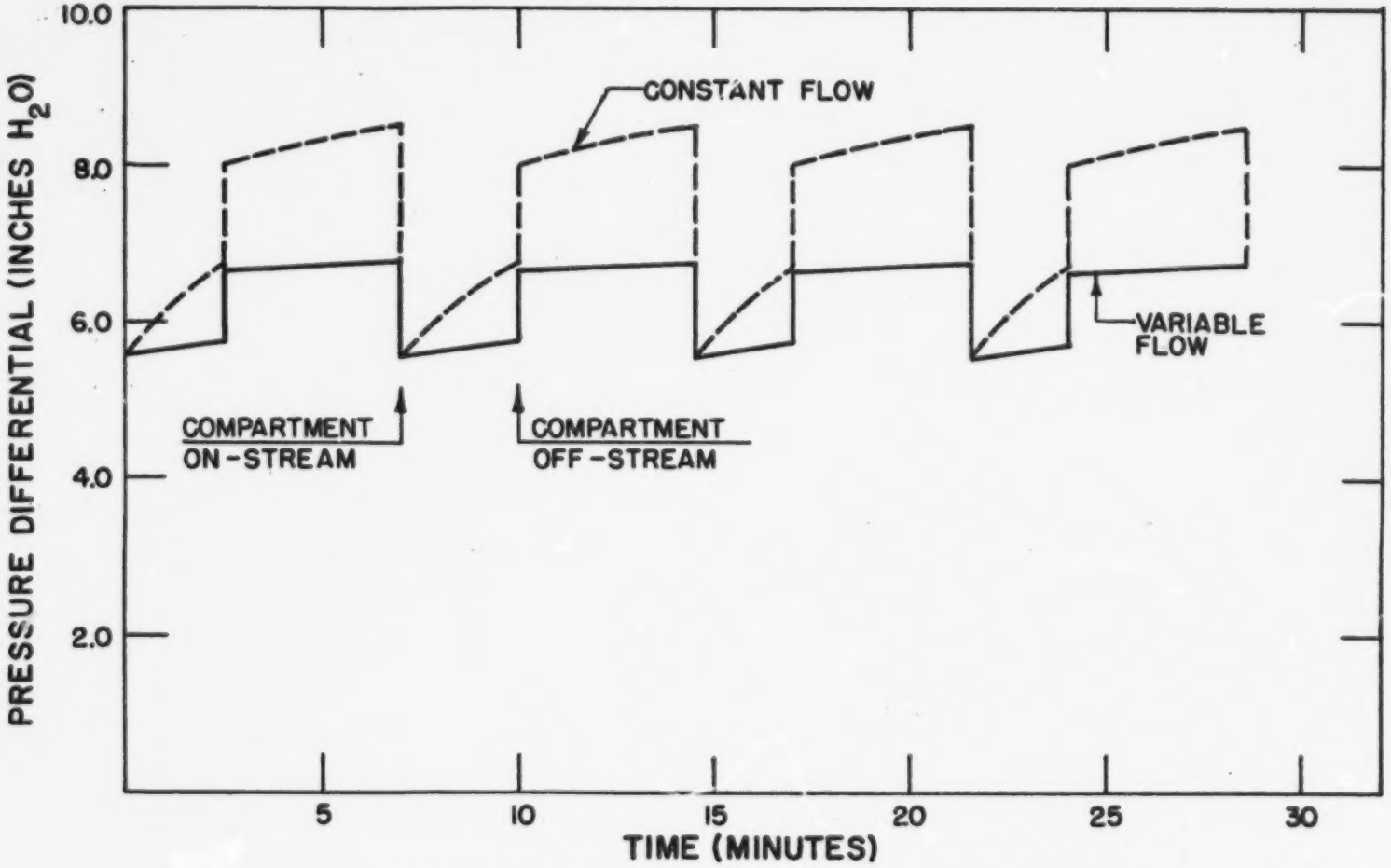
Field Considerations

The previous discussions have been limited to the performance of an ideal baghouse. It has been found, however, that variations from these ideal conditions do not detract from the utility of using filter drag as a property of the system to facilitate quantitative evaluation of a baghouse.

For instance, due to the nature of the fans used on most installations, a variation in flow rate occurs as the drag of a baghouse changes. An analysis of flow rate with cycle time is, therefore, a critical step in the characterization technique. For a house with a large number of units, operating with short cycle times, the variations will be minimized; when the number of compartments is small, the chances for significant differences are great, and they may completely obscure the true performance as reflected in pressure differential data alone.

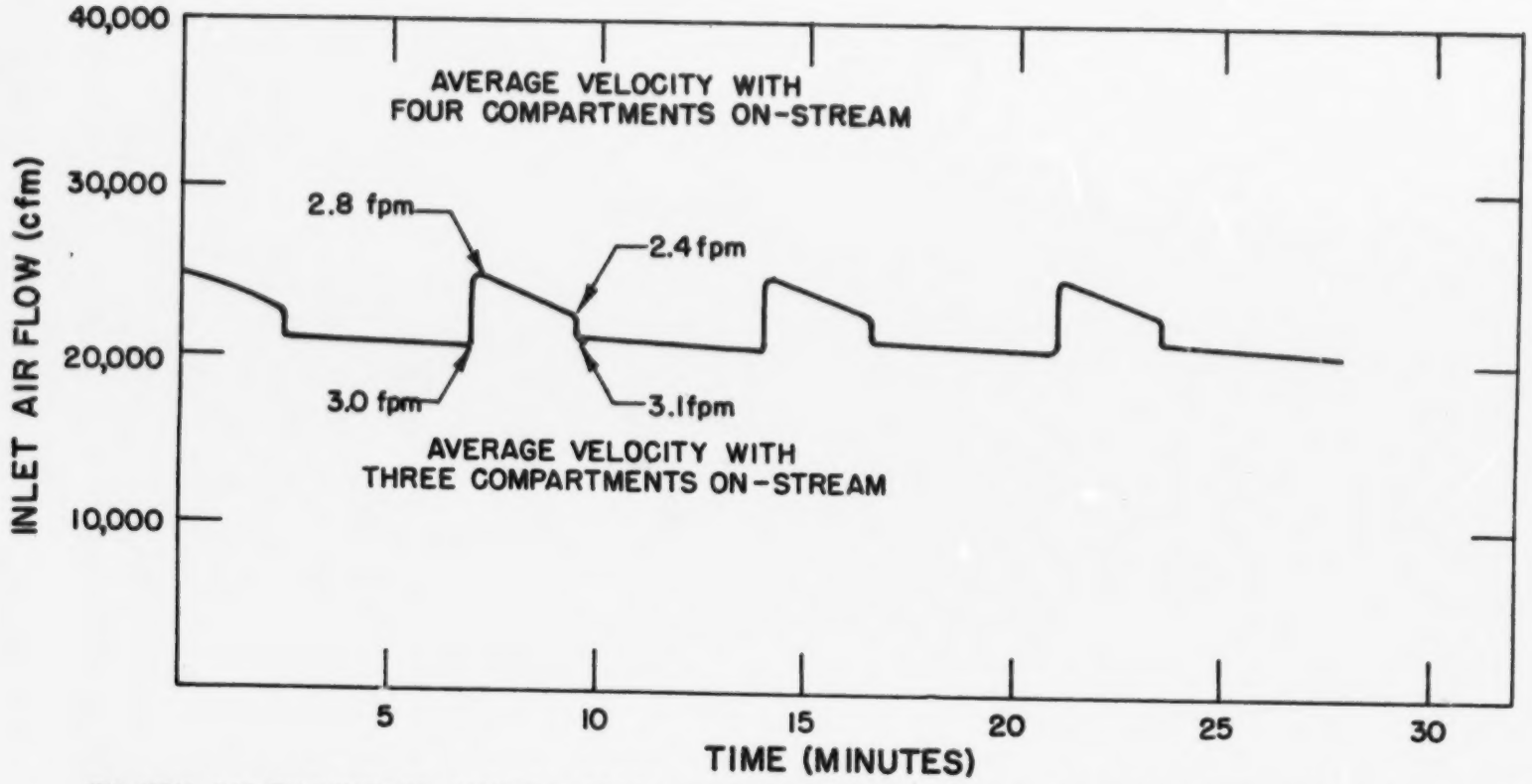
To illustrate this, consider the pressure differential curves for a four-compartment house collecting fume from an electric-arc process, as shown in Figure 4. Two curves are shown on this figure; the solid curve represents average pressure differentials recorded in the field; the dotted curve represents the pressure differentials that would have existed if flow were constant. It can be seen that there are material differences between respective values. The first curve tends to indicate very little change with time, while the second shows the opposite.

To obtain the curve representing constant flow conditions, it was necessary to correlate the volume of gas flow with cycle time, as shown in Figure 5. Filter drag values were then calculated for the critical



EFFECT OF FLOW VARIATION ON PRESSURE DIFFERENTIAL CURVE

FIGURE 4



FLOW VARIATION WITH CYCLE TIME FOR FOUR COMPARTMENT BAGHOUSE

FIGURE 5

8c

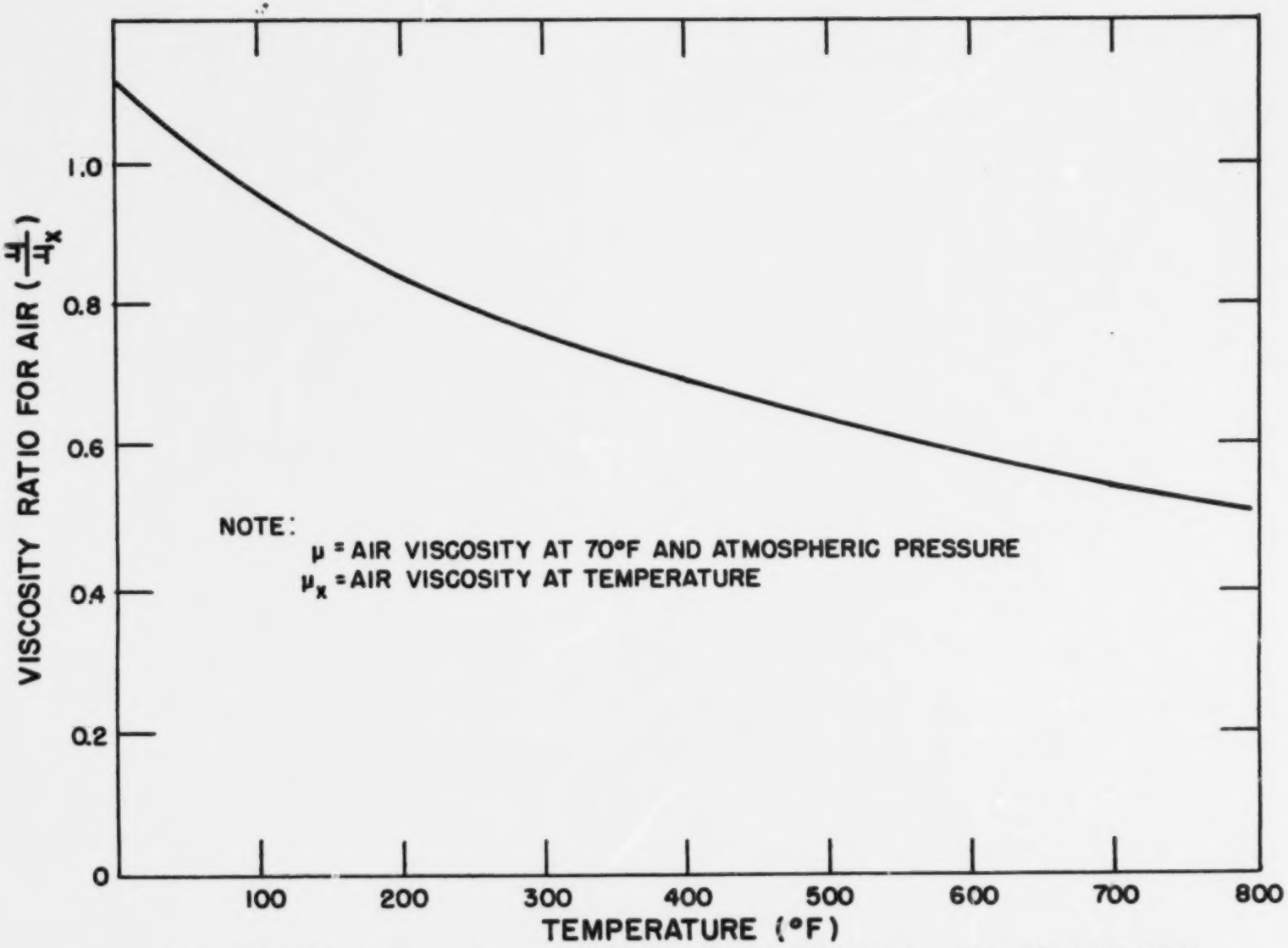
conditions as derived from Figure 3, and these values used to obtain the pressure differentials that would exist if flow were constant.

Temperature variations may introduce additional complications for the field investigator, inasmuch as the gas volume and viscosity are affected. The gas temperature as it passes through the filter media may differ from the temperature at the point where flow was measured; also, the temperature of the gas may vary with cycle time as well as from installation to installation. For the two latter situations an accurate characterization can be performed only when appropriate compensations are made.

Gas volumes, for example, must be corrected to the average temperature between the points where the pressure differential is measured. It may also be necessary to correct for temperature effect on viscosity, since filter drag is directly proportional to gas viscosity. To maintain drag as a function of the filter medium alone, the measured value must be corrected to represent conditions of constant viscosity. To accomplish this, the measured value is multiplied by a ratio of viscosities, according to the equation:

$$S = S'\left(\frac{\mu}{\mu_x}\right) \qquad (10)$$

where S is the standard filter drag, S' is the measured drag, μ is the viscosity at standard conditions, and μ_x is the viscosity of the gas passing through the filter medium. When air is the fluid flowing, viscosity ratios shown on Figure 6 may be used.



AIR VISCOSITY RATIO AS FUNCTION OF GAS TEMPERATURE

FIGURE 6

Entrance and exit losses to the compartments of a baghouse introduce slight errors in the characterization since the gas flow in these elements is turbulent and consequently the pressure differential across such elements is not directly proportional to flow. Therefore, when a compartment is put on stream and a redistribution of gas takes place, the resistance of the inlet and outlet elements of those compartments continually in service will change to a small degree. Where the number of compartments is large (say 6 or greater) and where frequent cleaning is employed, the gas volume to be redistributed will be relatively small and the changes negligible. In the unusual situations where a more exact value of the residual drag of the filter media in the compartment brought on stream is desired, it can be calculated from the maximum velocity at the start of filtration, as previously defined, and from additional pressure differentials measured from the clean air side to the dirty air side of the filter media in the individual compartment.

Utility of Critical Characteristics

For a fabric filter installation, operating difficulties often fall into one or more of the following groups: (a) high filter pressure differentials, (b) excessive filter wear, or (c) poor efficiency. In each situation, the critical characteristics will occur in a unique combination which reflects the nature of the operating cause. A number of combinations are summarized in Table 1. For example, high filter pressure differentials may be the result of infrequent cleaning, poor cleaning, a combination of the two, or severe aging. As shown in Table 1, poor cleaning will manifest

TABLE 1. OPERATING DIFFICULTIES RELATED TO CRITICAL CHARACTERISTICS OF BAGHOUSE

High Filter Pressure Differential		Excessive Filter Wear		Poor Efficiency	
Operating Cause	Critical Characteristics	Operating Cause	Critical Characteristics	Operating Cause	Critical Characteristics
Infrequent Cleaning	S_R Normal S_T High u_{f_r} High	Cleaning Too Frequently	Alter technique and study effect on performance by repeated characterization.	Infrequent Cleaning	S_R Normal S_T High u_{f_r} High
Poor Cleaning	S_R High S_T High u_{f_r} Low	Cleaning Time Too Long		Over-Cleaning	S_R Low S_T Low u_{f_r} Normal
Poor-Infrequent Cleaning	S_R High S_T High u_{f_r} High	Cleaning Technique Too Severe		Infrequent, Over-Cleaning	S_R Low S_T High u_{f_r} High
Severe Aging	S_R High S_T High u_{f_r} Normal	Dust Abrasion of Fabric	u_{f_r} High, Hence, Vertical Velocity in Filter is High	Wrong Fabric for Dust	S_R Normal S_T Normal u_{f_r} Normal

S_R = Residual filter drag.

S_T = Terminal filter drag.

u_{f_r} = Residual velocity.

itself in a residual drag which is high relative to the terminal drag, so that the residual velocity will be low. Infrequent cleaning, on the other hand, will be indicated by a high terminal drag relative to the residual drag, and the residual velocity will be high. When poor and infrequent cleaning are combined, the critical characteristics will all be high. If the filter drags are high but the residual velocity normal, then the high pressure differentials are the result of severe aging.

Unfortunately, absolute values of low, high, and normal cannot be given, since such data will be peculiar to specific dust-fabric combinations. It is felt, however, that the cause of an operating difficulty can be ascertained through characterization using the outlined three critical factors, especially when data are available since operation of the baghouse commenced. For example, in a study of two installations it was found that compartments were cleaned too frequently, giving rise to unnecessary filter wear. This conclusion was reached when it was found that the residual and terminal filter drags were close in value, while the rate of filter drag increase was very low. Altering the cleaning technique to produce one cleaning per compartment rather than four in a given time had no adverse effect on the critical characteristics. In another situation, it was evident that aging was the cause of high filter pressure differentials. Infrequent cleaning as a cause was eliminated since both the residual and terminal filter drags were high; poor cleaning did not apply, since the residual filter drag was reduced about 50% with cleaning; poor and infrequent cleaning was not an adequate explanation since the residual velocity was not a great deal higher than the nominal house velocity with one compartment off-stream.

Conclusion

It is concluded that knowledge of the critical characteristics of a particular baghouse is a new tool for evaluating operating performance and for assessing the effects of changes suggested by the evaluation. A compilation and analysis of data on a number of baghouse installations should be useful for delineating the dominant variables that influence bag filtration, for determining quantitatively the effect of these variables, and for developing empirical or semi-empirical relationships that will assist in the prediction of operating limits.

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